Investigation of tribological and thermophysical properties of base oil containing nanoparticles as additives

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Abstract

Engine oil is primarily used to carry away the excess heat from engine and to provide lubrication to moving parts of the engine, thereby reducing friction and wear between the rubbing surfaces. However with time net heat stored in the bulk of the engine oil becomes greater than its thermal conductivity causing a drastic reduction in its viscosity leading to formation of oil sludges inside the engine. Previous studies prove that the nano engine oil prepared by dispersing nanoparticles into engine oil provides enhanced operational characteristics when compared to plain engine oil, but are accompanied by the high cost of preparation and low stability of the nano engine oil[1]. In the present study a nano base oil which is a dispersion of MWCNTs and ZnO nanoparticles of ratio 1:4 in mineral oil was prepared by the two step preparation process. Tribological properties such as wear resistance, friction co-efficient and thermophysical properties such as thermal conductivity, viscosity, flash point of the nano base oil were evaluated and were compared with SAE 20W40 engine oil. The results obtained reveal that nano base oil possess better tribological and thermophysical properties when compared to engine oil, which will eventually improve the lifetime of the engine components. Copyright © 2018 VBRI Press.

Keywords: Multi-walled carbon nanotubes (MWCNTs), zinc oxide nanoparticles, tribological properties, thermal conductivity, engine oil.

Introduction

Engine oil, considered a pioneer in automobile sector, is used to carry away the excess heat generated in the IC engine due to combustion of fuel and friction between the moving parts of engine. Over prolonged usage, commonly used engine oils experience a problem of reduction in their lubrication properties due to decrease in viscosity with increase in temperature. Various studies were carried out by addition of nanoparticles to the engine oil to overcome the above mentioned problem. Ehsan *et al.*[2] and Bagavathi [3] used various metal oxide nanoparticles including copper oxide, aluminium oxide in the earlier stages due to their feasibility. Engine oil with different combinations of metal oxide nano additives were developed by researchers Kallakada *et al.*,[4], Baogang *et al.*[5]. This study compares the tribological and thermophysical properties of SAE 20W40 engine oil and the base oil containing a mixture of MWCNTs and ZnO nanoparticles as additives. A series of experiments have been carried out to test the operational characteristics of both engine oil and nano base oil. The experiments carried out produce results which implies the results obtained from a real time on road testing. Parameters that are significant for engine oil are tested by adopting high industrial standards. The unique idea behind this work is that instead of dispersing nano particles to engine oil, nano particles can be added to base oil which serves as the base for engine oil

Drawbacks of previous studies

Though the major problem faced by the commonly used engine oil was solved by dispersion of nanoparticles, there were few other drawbacks associated with the nano engine oil. The main problems were the high cost of the nanomaterial and the loss of stability of the prepared nano engine oil over prolonged usage due to aggregation by sedimentation and agglomeration. Though the surfactants were used to solve the problem of agglomeration of nanoparticles, the usage of surfactant affected the heat transfer properties of the nanofluids at elevated temperatures as stated by Xiang *et al.*[7]. Due to the reduction in the effect of dispersion, blocks are formed in the engine which may lead to engine failure at extreme conditions. To overcome this, we dispersed a very small volume amount of the solute with the total nano particle volume fraction of 0.025% in the mineral oil base fluid.

This reduces in the cost of preparation of the lubricant. Also the stability of the prepared nano base oil was high due to the very small nanoparticle concentration without usage of any surfactant. The volume fraction of MWCNTs and nano ZnO in the base oil was in the ratio 1:4.

Experimental

Table 1. Specifications of SAE 20W40 Engine Oil and Mineral Base Oil.

Specification	SAE 20W40	Mineral Base Oil
1. Density at 30^0	800 kg/m^3	852 kg/m^3
2. Viscosity at 30^0	103 cm^2/s	142 cm^2/s
3. Viscosity at 100^0	9.2 cm^2/s	12 cm^2/s
4. Thermal Conductivity	0.135 W/mk	0.134 W/mk
5. Flash Point	243^0C	212^0C

Preparation of nano base oil

In general, nanofluids can be prepared by one step preparation process and two step preparation process. In this study the nano base oil was prepared by the two step preparation process. Nano base oil, a nanofluid was prepared by dispersing nanoparticles into the mineral oil. A volume fraction of 0.005% of MWCNTs and 0.02% of nano ZnO was added to the base oil and the mixture was subjected to constant stirring in a magnetic stirrer for a duration of 1 hour, followed by ultrasonification in an ultrasonic agitator for 3 hours to obtain a stable nanolubricant.

Fig. 1. Nano Base Oil.

Measurement of thermal conductivity

Thermal conductivity is the heat transferring ability of a fluid. Addition of nanoparticles to the base oil enhances the thermal conductivity of the base fluid [1]. The thermal conductivity of nano base oil was measured by using KD2 Pro, a portable device which works on the principle of the transient line heat source method. The thermal conductivity was measured at College of Engineering, Guindy, Chennai.

Measurement of tribological properties

Tribology is the study of friction, wear and lubrication. Analysis of tribological properties helps to estimate the life time of the engine. The properties of base oil containing nanoadditives were estimated by using Pin-on-Disc tribometer at Met Mech Engineers, India and compared with the properties of plain engine oil. The tribometer consists of a stationary pin and rotating disc with lubrication setup. Constant load which is chosen based on the average load applied on vehicles, is applied under stationary pin to make contact with the rotating disc. The setup resembles the piston and cylinder of the engine where piston slides over the cylinder with nano base oil and engine oil as lubricants. Two cylindrical pins with rounded ends and rotating disc of different materials were used as specimens. The tribological properties of nano base oil and engine oil were estimated and compared with one another.

Table 2. Operational Characteristics of Pin on Disc Tribometer.

Specification	Value
1. Rotation speed of Disc	1136rpm
2. Load on Pin	40N
3. Sliding Velocity	4.2m/s
4. Testing Time	600seconds

Measurement of viscosity

Viscosity is the ability of fluid by virtue of which it offers resistance to flow of one layer of the fluid over another adjacent layer. In this study, the viscosity of two 50 ml samples namely plain engine oil and nano base oil were estimated using Redwood viscometer. Viscosity is one of the main properties of a lubricant which has to be maintained at an optimum level. Increase in viscosity beyond a limiting value obstructs the flow and when decrease in viscosity shrivels the thickness of the lubrication layer leading to increased wear. Viscosity of the prepared nano base oil was studied at both room temperature and at an elevated temperature of 100^0C by heating the engine oil and nano base oil.

Measurement of Flash point

Flash point is the temperature at which an organic compound gives off sufficient vapour to ignite in air. Flash point of engine oil and base oil containing a mixture of nanoparticles was studied more precisely using Pensky-Martens closed cup apparatus, which is one of the most commonly used device to estimate the flash point of petroleum products.

Results and discussion

Tribological properties

Wear resistance and friction reduction properties

From the wear results of Pin on Disk Tribometer, the nano base oil possessed better wear resistance property than that of the plain engine oil. Nano base oil exhibited an average wear of about 113 microns whereas, the plain engine oil exhibited a wear value of 138 microns. Base oil containing nanoparticles exhibited wear reduction of about 18.16% when compared to that of the plain engine oil. Negative wear is due to high interferential strength of the nanoparticles, which causes the pin to move upward and this is highly related to high mechanical strength of multi-walled carbon nanotubes.

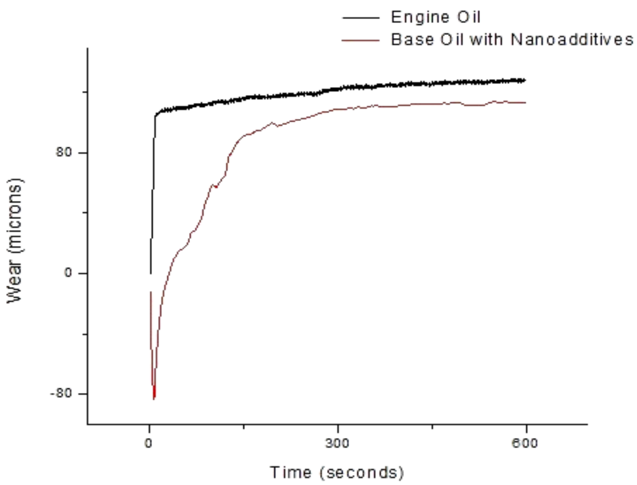

Fig. 2. Graph showing variation of wear between plain engine oil and nano base oil.

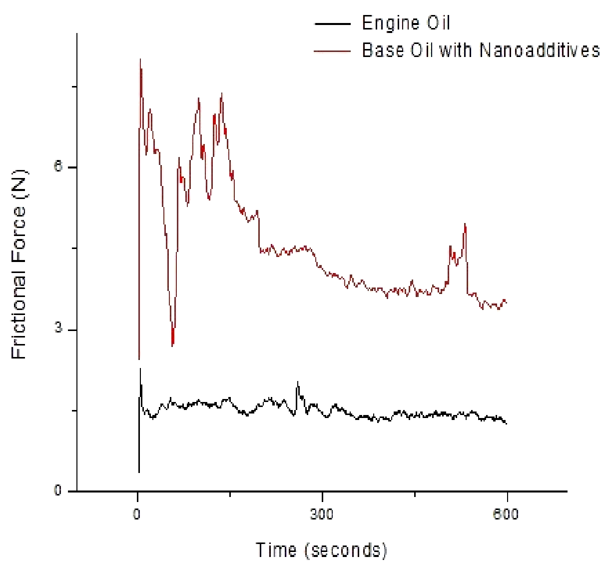

Fig. 3. Graph showing variation of frictional factor between plain engine oil and nano base oil.

Though the frictional force values of the base oil containing nanoparticles were high when compared to that of the plain engine oil, the values were in concern with the pin and lubrication layer. The values are not concerned with the friction between the pin and disc and thus can be neglected. The increased frictional and wear resistance values are due to direct effects such as rolling, filming, sliding and surface enhancement effects such as mending and polishing associated with the usage of nanoparticles.

Kinematic viscosity

Plain engine oil exhibited a kinematic viscosity of about 132 stokes at 303K and 13 stokes at 373K while the base oil containing a mixture of nanoparticles showcased a kinematic viscosity of about 177 stokes at 303K and 14.778 stokes at 373K. The reason behind the increased kinematic viscosity is the addition of nanoparticles in the base oil. Basically when any solute is added to a solvent, the viscosity value of the resulting solution increases. Nano base oil exhibited an enhancement of about 24.68% and 23.15% at 303K and 373K. This serves as one of the primary reason for the better lubrication properties of nano base oil.

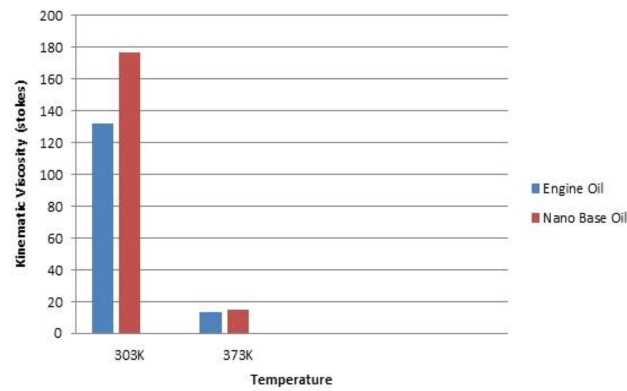

Fig. 4. Kinematic viscosities of plain engine oil and nano base oil at 303K and 373K.

Thermal conductivity

Addition of any solute to a solvent constitutes to an increased Brownian movement in the solvent which in turn improves the thermal conductivity of the solvent. Thermal conductivity of plain engine oil was measured to be 0.135W/mK whereas the thermal conductivity of nano base oil was measured to be 0.148W/mK. An enhancement of about 9.6% in the thermal conductivity of the base fluid was observed by dispersion of 0.005% vol of MWCNTs and 0.02% vol of ZnO nanoparticles. Due to the increased thermal conductivity, the heat stored in the bulk of the mineral oil will reduce which will result in reduced chances of formation of oil sludges inside the engine.

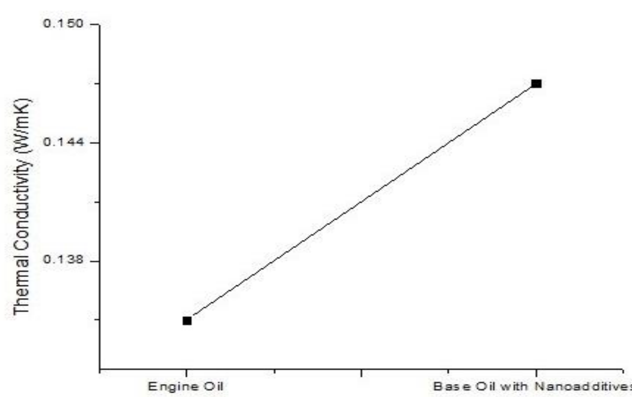

Fig. 5. Thermal conductivity of plain engine oil and nano base oil.

Flash point

Engine oil exhibited a flash point of about 243^0C, whereas base oil containing a mixture of nanoparticles showcased a value of around 251^0C. Nano base oil exhibited an enhancement of about 3.29% when compared to that of the engine oil. Higher flash point means that the prepared nanolubricant requires a higher temperature for burning compared to that of the conventional lubricant

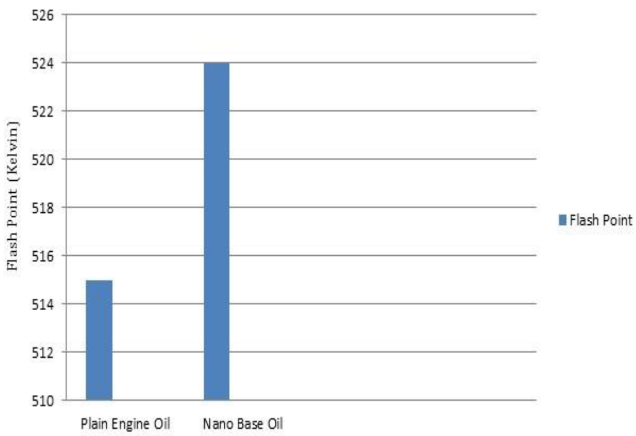

Fig. 6. Flash point of plain engine oil and nano base oil.

Conclusion

Thus, it is evidential from the results that the base oil containing nanoparticles exhibited better tribological and thermophysical properties compared to the commonly used SAE 20W40 engine oil. Nano base oil thus proves to be an effective replacement to the commonly used engine oil both in terms of cost and functioning. Further studies are to be carried out on the rheological, heat and mass transfer properties of the nano base oil to impart theoretical explanations to the current study.

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